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APPLICABILITY OF SO₂-CONTROL PROCESSES
TO POWER PLANTS.

J. A. McSorley

Kellogg (M. W) Company

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PB 213 421

ENVIRONMENTAL PROTECTION TECHNOLOGY

Applicability of SO₂-Control Processes to Power Plants



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Applicability of SO₂-Control Processes to Power Plants

by
M. W. Kellogg Company
Piscataway, N. J.

Contract No. CPA 70-68, Task 11
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APPLICABILITY OF SO_2 -CONTROL PROCESSES
TO POWER PLANTS

TASK #11 FINAL REPORT

CONTRACT NO. CPA 70-68

Submitted to

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS
CONTROL SYSTEMS DIVISION

by

THE M. W. KELLOGG COMPANY
RESEARCH & ENGINEERING DEVELOPMENT
HOUSTON, TEXAS



APPLICABILITY OF SO₂-CONTROL PROCESSES
TO POWER PLANTS

TASK #11 FINAL REPORT

Submitted to
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS
DIVISION OF CONTROL SYSTEMS
Contract No. CPA 70-68

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APPLICABILITY OF SO₂-CONTROL PROCESSES
TO POWER PLANTS

TASK #11 FINAL REPORT

EPA-OAP-DCS CONTRACT NO. CPA 70-68

OCTOBER 15, 1972

Staff: M. J. Cambon, L. D. Fraley, J. J. O'Donnell
and A. G. Sliger

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Authors:

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A. G. Sliger

ABSTRACT

In this and a previous similar study completed in early 1971, 14 different power systems were evaluated having a total oil- and coal-fired generating capacity of 88,520 megawatts of which 79% had adequate space for retrofitting scrubbers. The results are summarized below:

No. of Plants		Generating Capacity, MW	Capacity with Space for Scrubbers	
			MW	%
Present Study	62	61,270	53,822	88
Previous Study	41*	27,250	15,890	58
	103	88,520	69,712	79

*Not reevaluated in present study.

Most of the systems and plants covered by the 1971 study also were included in this more detailed study. However, limitations on both funds and time available for the study dictated selections of systems with readily available data and the largest number of plants which naturally resulted in large systems being studied. Thus, while both studies covered a total of 49% of the capacity, this comprises only 15% of the plants, basis 1970 oil- and coal-fired plants.

To obtain an indication of installation costs, a qualitative retrofit complexity factor was estimated for each boiler unit studied by considering such items as space availability, site assessability, and degree of plant modification. The complexity factor relates the cost of retrofitting a control system to the cost of the same system installed on a new power plant. Thus, a control unit on a new power plant would have a complexity factor of 1.0 while a factor of 3.0 was assigned to a very difficult retrofit installation. Any unit without adequate space for retrofitting a scrubber was rated above 3.0. The estimated complexity factors were distributed evenly from 1.5 to 3.0 over the surveyed capacity, but there were trends toward lower

factors in the larger, newer units. The average complexity factor for units older than 20 years and smaller than 100 MW was 3.0; the average for units younger than 10 years and larger than 500 MW was 2.0.

The distribution of relative operating costs (levelized to an average annual basis) over generating capacity was calculated by assuming that investment is proportional to the complexity factor and by incorporating the effect of the unit load factor. On this basis it was found that 50% of the generating capacity can be retrofitted at a relative cost per kilowatt-hr of 1.7 to 2.4-fold the cost of installing the same control units on new power plants operating at full load.

Several other applicability factors were included in this study, but the data obtained were insufficient to permit any general conclusions to be reached. These factors include:

- Available space for regeneration facilities
- Available land for waste disposal
- Present technique and costs of fly ash disposal
- Availability and cost of utilities, clean fuels and other materials.

A final point to be noted is that while many utilities have scrubber space available, they are presently switching to low sulfur fuel and many have made long term commitments with the fuel supplier. Essentially all of the utilities contacted stated that they would prefer low sulfur fuel to stack gas clean-up if such fuel is available.

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I. PREFACE

The work described herein in general represents an effort to determine the extent to which SO₂-control units can be installed in existing oil- and coal-fired power plants. Ideally, a detailed evaluation should be made of all the major factors influencing the installation of the control unit with plants selected to provide a completely representative cross section of the power industry. However, the calendar time and man-hours allocated to perform the work coupled with the need to obtain certain minimum results limited the degree of detailed evaluations that could be made. Also limiting the degrees of freedom was the requirement that a maximum of nine different companies could be contacted since the proper clearances to contact more than this would have extended the calendar time beyond the specified limit. Consequently, the need to obtain a maximum amount of data in a limited time from only a few companies resulted in the selection of large utilities as the source of information. Before the work was started, the concurrence of the EPA task officer was obtained for both the list of utility companies to be studied and the questionnaire that would be used.

Since the larger utilities generally have the largest and newest plants compared to the overall national average, the results do not represent a true cross section of the power industry. On the other hand, the majority of the power generated in this country is produced by a relatively few power plants, percentage wise, so the results should correlate well with overall generating capacity.

The geographical locations of the plants were selected to provide data from each section of the contiguous U.S. with both urban and rural sites covered. Primary emphasis was on space availability but cost also was considered indirectly by assuming

that control units costing more than about \$75/KW would not be used. Instead, it is expected for this situation that some alternative, such as low sulfur fuel, would be found.

Conclusions based on the results of this study should consider the limitations of the study, the major ones being those cited above. Within these limitations, however, the results should be quite useful in providing a reasonably accurate picture of the applicability of SO₂-control units to existing power plants.

II. INTRODUCTION

This report covers work which was performed under Contract No. CPA 70-68, Environmental Protection Agency, Office of Air Programs. The task specifications were delineated by OAP in Task No. 11 Contract Task Specification Request, dated November 17, 1971, and supplemented by an OAP letter dated December 20, 1971, which transmitted additional input data to be used in the study.

Task Order No. 11, in short, specifies that a survey be made of the power utility industry to ascertain the degree to which SO₂-control processes can be installed (as retrofit units) in existing and new power plants. Space considerations were of primary concern but other factors also were to be considered, such as general mode of transportation, disposal of waste materials, availability of utilities, etc. A previous Kellogg study of very limited effort had considered space limitations only and the present study was to include and expand this earlier study. The purpose of the study is to provide OAP with more specific information than presently available as to the application to existing plants of the SO₂-control processes now receiving OAP support, thereby insuring that research and development funds are channeled into areas where maximum benefits will result.

To provide a basis for determining space requirements, EPA specified six different processes as the basis for this study, viz.:

- Limestone slurry scrubbing
- Lime slurry scrubbing
- Magnesium oxide scrubbing with regeneration
- Ammonia scrubbing - Bohna regeneration
- Sodium scrubbing - Wellman-Lord (Wellman-Power Gas, Inc.)
- Sodium scrubbing - Stone and Webster/Ionics

Since all of these processes employ wet scrubbing to remove the SO_2 from the flue gas, essentially the same size scrubber could be used in all cases. Further, to minimize space requirements, it was decided to include a dust removal section in the bottom of the wet scrubber rather than having a separate fly ash control system. Information for the fly ash scrubbing section of the tower was obtained from an equipment vendor who has many commercial installations for similar service and will guarantee greater than 99% efficiency. The additional space for the dust scrubbing step is small so whether or not there is existing dust control equipment in the plants studied has no effect on the overall results.

Cost estimates of installation the SO_2 -control systems were desired but even very rough estimates would have required more time and effort than were available so this parameter was not studied. To provide a general idea of the cost of retrofitting, however, a complexity factor (largely subjective) was estimated for each unit studied; this factor gives the ratio of a retrofit cost to that of a new plant. The complexity factor was estimated in each case by evaluating the effort required to retrofit a control system considering qualitatively the modifications needed such as moving parking lots and/or buildings; relocating solids storage piles, railroad tracks and roads; structural alterations needed; accessibility of scrubber site, etc. The values assigned to the complexity factors range from 1.5 to 3.0, based on very limited input information for units actually being installed. Thus, a very difficult retrofit might cost three-fold as much as units installed on a new plant.

III. ACKNOWLEDGEMENTS

The cooperation and assistance of the many persons within the power utility industry who helped assemble the data reported herein is gratefully acknowledged. The individuals are too numerous to list here so the following tabulation comprises those companies that provided assistance, information and working space to the Kellogg personnel performing this evaluation.

- Arizona Public Service Corporation
- Boston Edison Company
- Commonwealth Edison Company
- Consolidated Edison Company of New York, Inc.
- Detroit Edison Company
- Duke Power Company
- Georgia Power Company
- Monogahela and Western Pennsylvania Power Company
- Pennsylvania Power and Light Company
- Philadelphia Electric Company
- Public Service Company of Indiana, Inc.
- Public Service Electric and Gas Company (New Jersey)
- Ohio Edison Company
- Tennessee Valley Authority

IV. SUMMARY AND CONCLUSIONS

A total of 14 different power systems were studied in this and the previous similar study completed in early 1971. The 1971 study considered only space limitations whereas the present study expanded the variables studied to include waste disposal, availability of utilities and raw materials, mode of transportation, etc. A complete listing of the criteria used in the evaluation is included in Section IV of this report -- Basis of Evaluation.

The 14 systems studied had a total of 103 plants of which 62 plants were included in the present study. The total generating capacity of the plants studied and the capacity which can be retrofitted with control units are as follows:

<u>No. of Plants</u>		<u>Generating Capacity, MW</u>	<u>**Capacity For Retrofit Scrubbers</u>	
			<u>MW</u>	<u>%</u>
Present Study:	62	61,270	53,822	88
Previous Study:*	<u>41</u>	<u>27,250</u>	<u>15,890</u>	<u>58</u>
TOTAL	103	88,520	69,712	79

*Not re-evaluated in present study

**Based on criteria established for this study, viz., primarily space availability and cost factors not exceeding about \$75/KW for the retrofit control unit.

The above results indicate that the majority of existing power plants studied can be equipped with an SO₂-control unit. Therefore, the major conclusion arising from this study is that based on the criteria established and assuming a representative sampling was obtained, SO₂-control units can be installed in existing power plants which account for nearly 80% of the present generating capacity in the contiguous U.S.

The following tabulation serves to put the present study in perspective.

Generation Method	*Installed Capacity, MW		Percent Studied	
	1970	1972 ²	1970	1972
Oil and Coal	182,191 ¹	212,943	49	42
Total Thermal	265,584 ³	308,613	33	29

*Contiguous U.S.

The above values show that a large fraction of the total U.S. generating capacity was studied and implies that results should be representative of the entire country. If, however, instead of capacity the number of plants is considered, the percentage studied drops from 49 to 15, basis 1970 oil- and coal-fired plants. This indicates that a high number of large size plants were included in this study and therefore conclusions reached based on the present data should differentiate between capacity and number of plants, the former being more significant.

To provide an indication of the cost involved for each unit where a control unit can be installed, a complexity factor has been derived. This factor shows the cost of a retrofit control unit relative to the cost of an identical unit installed in a new power plant and ranges from 1.5 to 3.0. Since specific cost estimates were not part of this study, the factor is strictly qualitative and was derived by estimating the difficulty of installing the control unit considering such items as space availability, site accessibility and degree of modification required to the site, buildings, structures and equipment. The range was selected based on the few values reported in the literature for the wet limestone scrubbing process for new and retrofit units. New complete plant installation fall in the range of \$20-25/KW while retrofit units can cost as much as \$60-70/KW for very difficult installations (i.e., limited space and poor accessibility). The complexity factors are shown in Table 8 for each unit studied.

¹"Steam-Electric Plant Factors/1970 Edition", Twenty-First Edition, February 1972 National Coal Association

²Based on data in FPC News, Vol. 5, No. 12, 3/24/71

³Calculated assuming nuclear comprises 2% of total thermal capacity

To further illustrate these cost data, the generating capacity which can be retrofitted with control units has been subdivided as a function of the complexity factors and the results are summarized in the following tabulation:

<u>Complexity Factor</u>	<u>Retrofit Generating Capacity, MW</u>	<u>*Percent</u>	<u>*Cumulative Percent</u>
1.0	1,037	1.17	1.17
1.5	26,853	30.34	31.51
2.0	9,333	10.54	42.05
2.5	16,012	18.10	60.15
3.0	<u>16,477</u>	<u>18.61</u>	78.76
	69,712	78.76	

*Based on total capacity studied -- 88,520 MW

Based on these data it is concluded that about 42% of the generating capacity studied can be retrofitted with SO₂-control units at a complexity factor of 2.0 (~\$50/KW) or less. The data are presented graphically in Figure 6 in Section VI of this report.

To provide an indication of the increase in power production costs owing to the installation of SO₂-control units, the complexity factor was used in conjunction with the load factor to calculate operating costs. The results of this calculation indicate that about 50% of the generating capacity studied could be retrofitted at relative incremental unit power costs of 3.5 or less which corresponds to an actual incremental power cost of about 2.0 mills/kwh, based on capital costs only. Other costs would add an additional 0.5-1.5 mills/kwh so that the total incremental power costs attributable to SO₂-control would be 2.5-3.5 mills/kwh.

A discussion and example of the method of calculating the incremental power costs owing to the SO₂-control units is included in Section VI of this report.

One objective of the survey was to ascertain if adequate utilities (primarily steam and/or power) are available to operate the control units, especially during peak power demand periods, once they are installed. In general, this information was not available in specific form; rather, the utilities stated that while the control units could be operated, the overall power grid would be affected and provisions for these control units would have to be included in plans for future expansion. In some cases power for the control units would have to be purchased during peak periods while in others, adequate reserves are available to supply the additional 1-3% needed.

Specific information generally was unavailable, (i.e., not known) regarding raw material supplies, potential by-product markets, future levels of SO_2 -control expected, or quantities of waste material (e.g., CaSO_4) that could be discharged into local water streams. It appears that separate, extensive studies would be required for each of these variables to develop this information and further, some items are not known at the present time, i.e., water quality restrictions and future SO_2 levels allowable.

Since water quality data generally are not known, space requirements only were considered in determining waste disposal facilities. In some cases, no on-site space is available and present practice is to pay outside contractors to haul the solid waste (i.e., fly ash) away. To dispose of the wet scrubbing waste material in this manner can cost up to \$7/ton, including the necessary drying equipment. In other cases, costs as low as \$0.40/ton are realized when disposal areas are nearby and no pretreatment is necessary. Considering the wide range of costs involved, no meaningful general conclusions can be drawn regarding waste disposal costs.

A final point to be noted is that while many utilities have scrubber space available, they are presently switching to low sulfur fuel and many have made long term commitments with the fuel supplier. Essentially all of the utilities contacted stated that they would prefer low sulfur fuel to stack gas clean-up if such fuel is available.

V. BASIS OF EVALUATION

Space requirements for both scrubbing and regeneration facilities were based on six different processes specified by OAP as follows:

- Limestone slurry scrubbing
- Lime slurry scrubbing
- Magnesium oxide scrubbing with regeneration
- Ammonia scrubbing - Bohna regeneration
- Sodium scrubbing - Wellman-Lord (Wellman-Power Gas, Inc.)
- Sodium scrubbing - Stone and Webster/Ionics

Based on both in-house data and information supplied by OAP, MWK prepared equipment layouts for the scrubbing section of each process. Space requirements for the appropriate regeneration sections were tabulated based on the limited information available at the time. Layouts and regeneration requirements, most of which were obtained from OAP, are shown in the following pages, Tables 1-6, and Figures 1-5. Note that the layouts show only the major pieces of equipment that have to be located adjacent to the power-house/stack since the smaller items (e.g., pumps) have only relatively small space requirements and should present no installation problems. Also, items such as structures, instruments, etc., likewise are not shown since they do not influence the layout to any great extent with respect to the present objective. The scrubbing equipment layouts are felt to be well established whereas the regeneration requirements are approximate. However, since the scrubbing space is the most critical requirement, (the regeneration section does not necessarily have to be adjacent to the power house/stack,) the lack of detailed data for regeneration area requirements does not adversely affect the study.

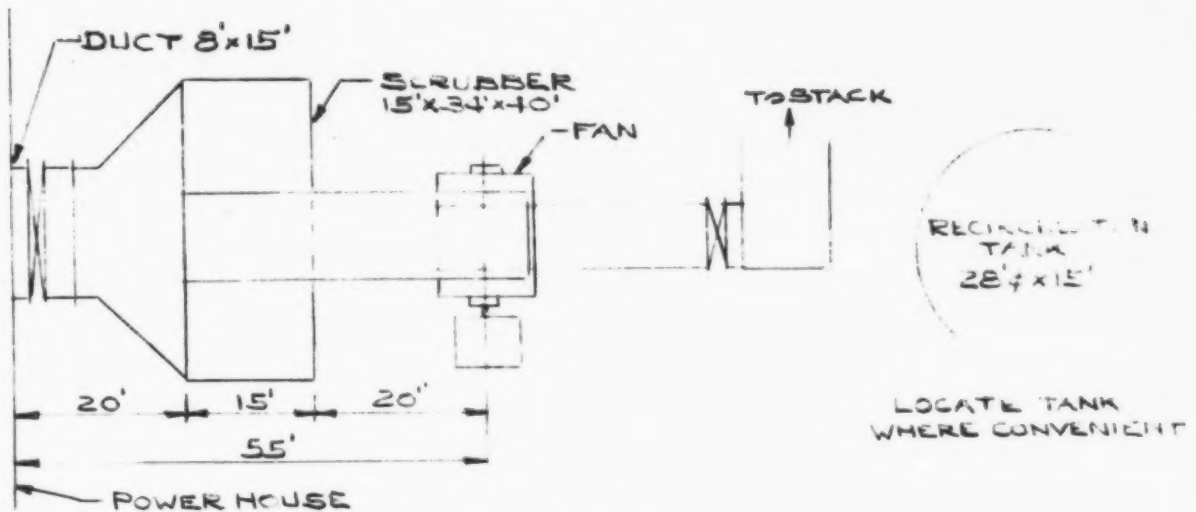
The evaluation procedure comprised personal visits to the selected power utilities, and, using the pilot plans and space

requirements shown, plot plans of the individual power stations were examined to determine if space were available in which the control units could be installed. The plot plans also were used to estimate the degree of modification to the power plant needed to install the control unit from which the complexity factor was derived. Other data needed for the survey were requested from the power plant personnel. The information related to plant operation generally, but not always, was readily available but the other data, e.g., water quality requirements, raw material availability, by-product markets, etc., were, in most cases, not known.

The specific items for which data were requested are shown in Table 7.

Figure 1

Wet Limestone & Lime Slurry - 167 MW



PLAN

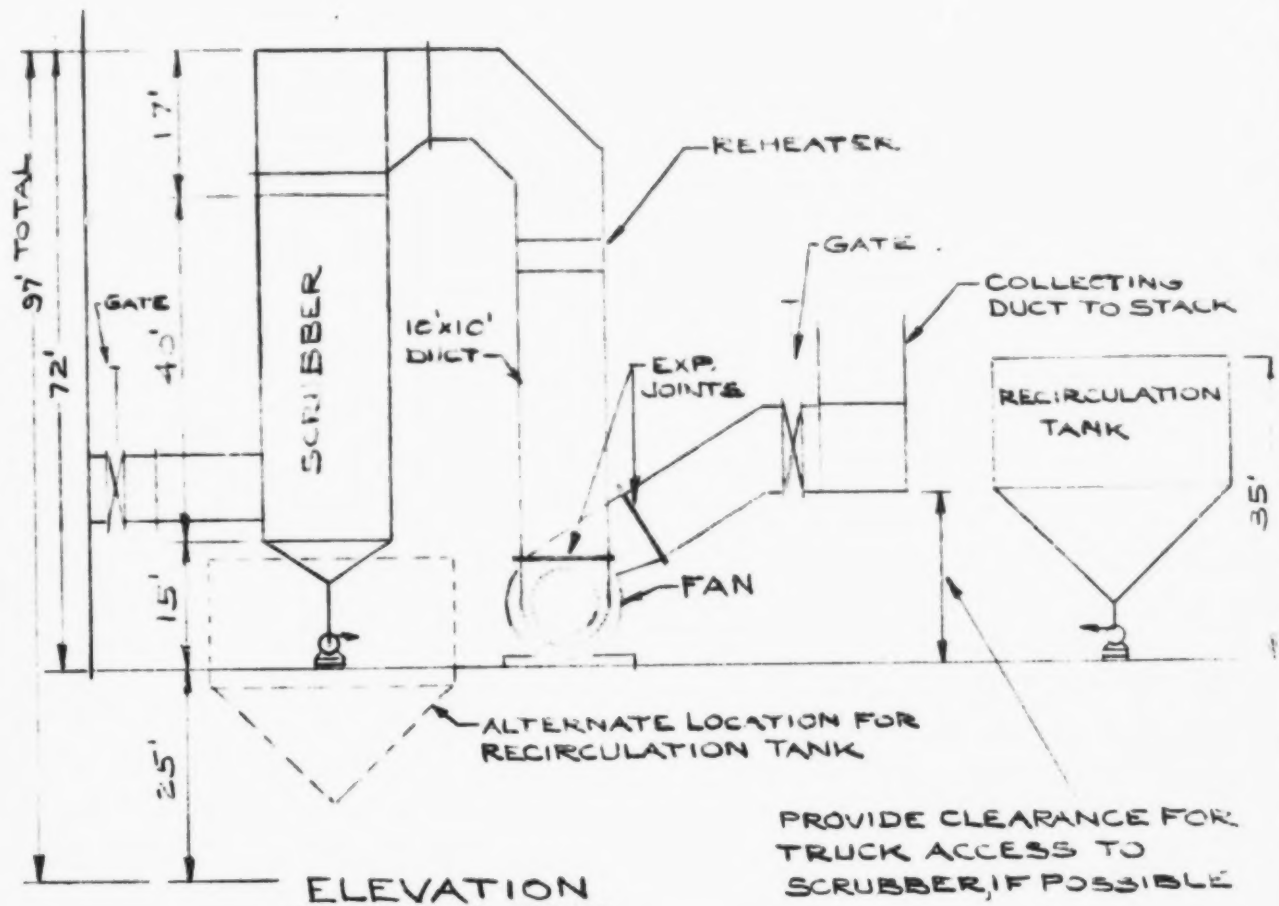
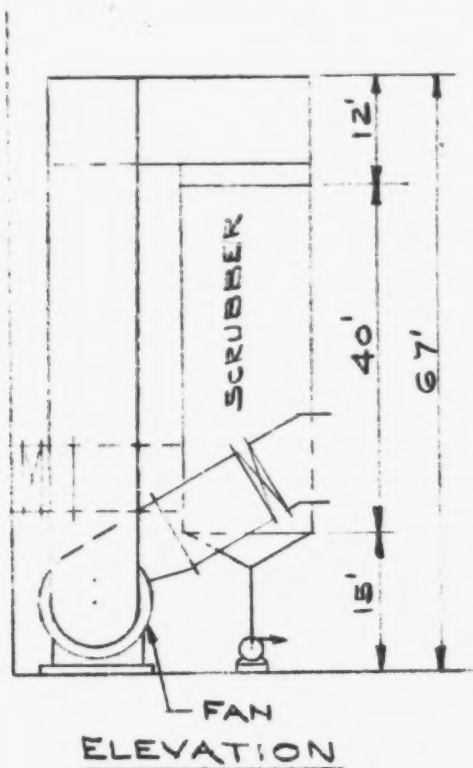
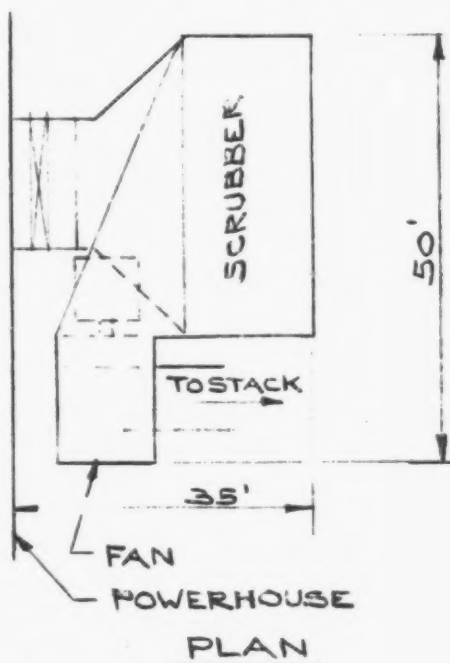


Figure 2

Limestone, Lime and MgO - Alternate Arrangement - 167 MW



Magnesium Oxide - 167 MW

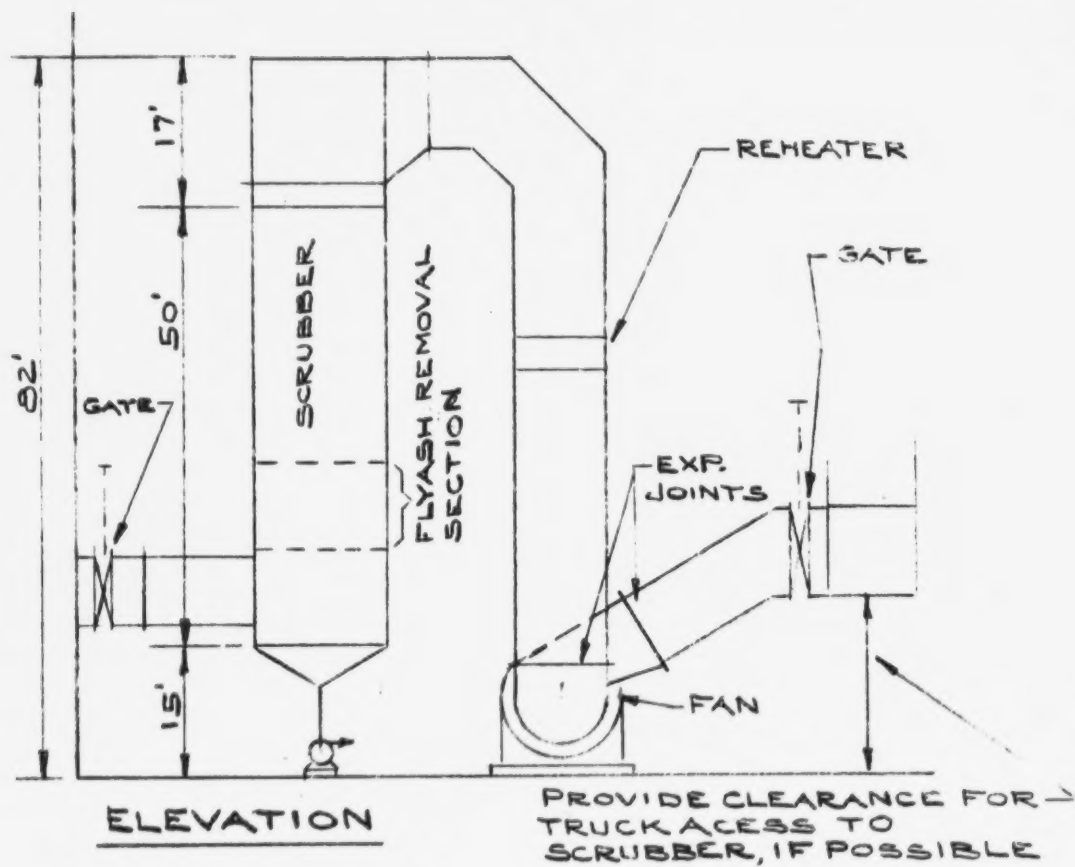


Figure 4

Ammonia Scrubbing - Bohna Regeneration;

Sodium Scrubbing -- Wellman-Lord;

Sodium Scrubbing -- Stone and Webster/Ionics - 167MW

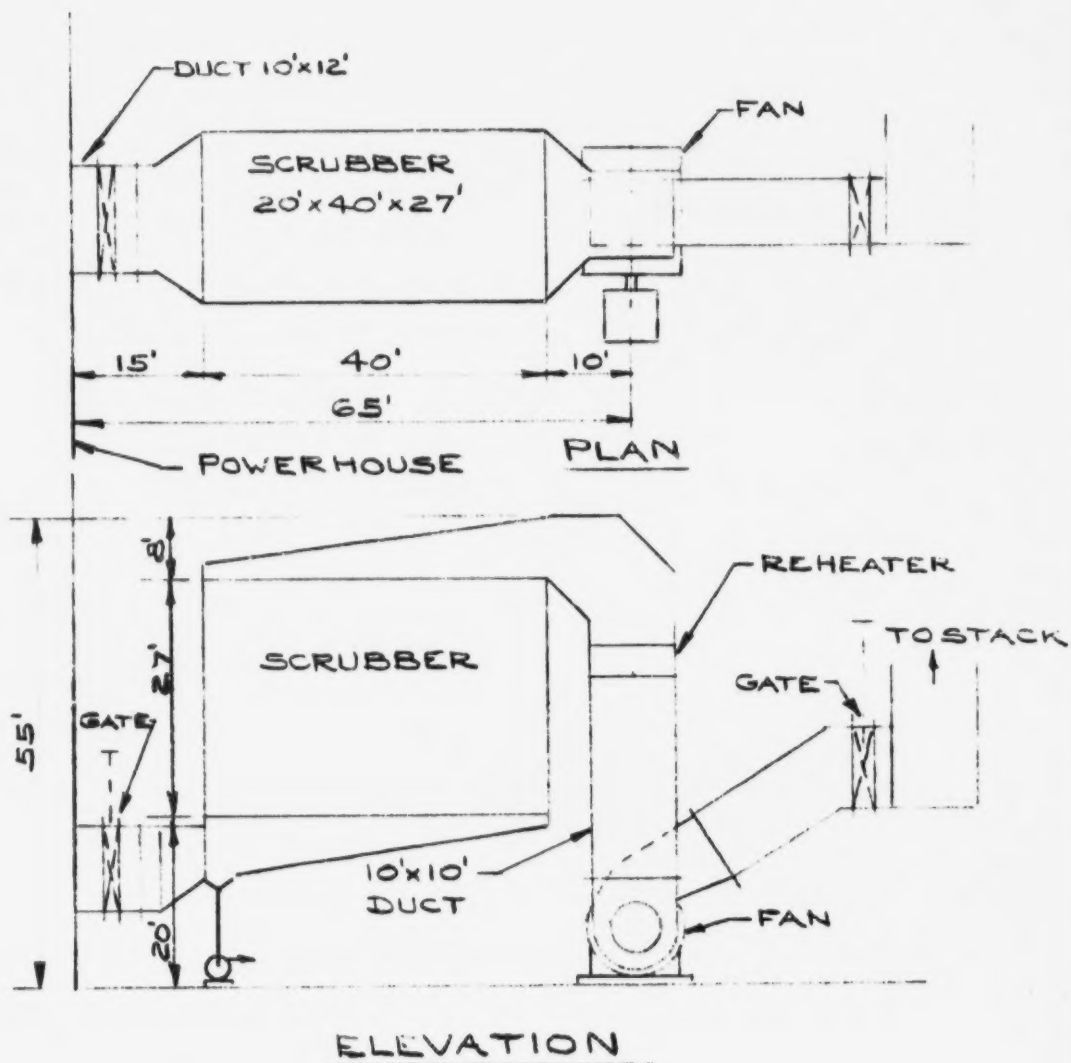


Figure 5

Ammonia Scrubbing -- Bohna Regeneration;

Sodium Scrubbing -- Wellman-Lord;

Sodium Scrubbing -- Stone & Webster/Ionics - Alternate Arrangement -167MW

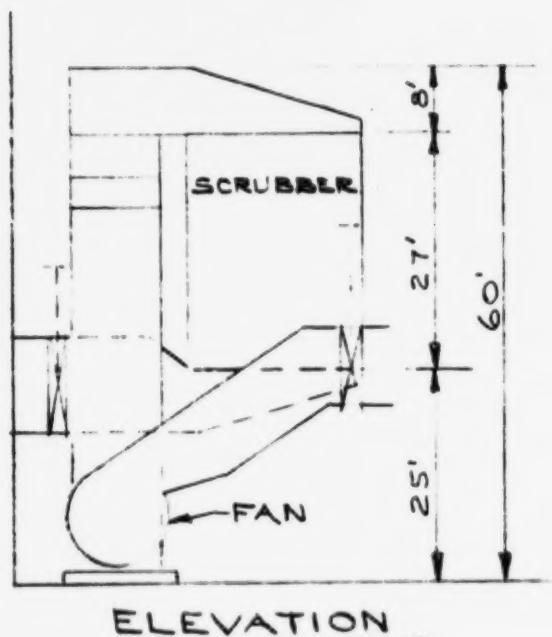
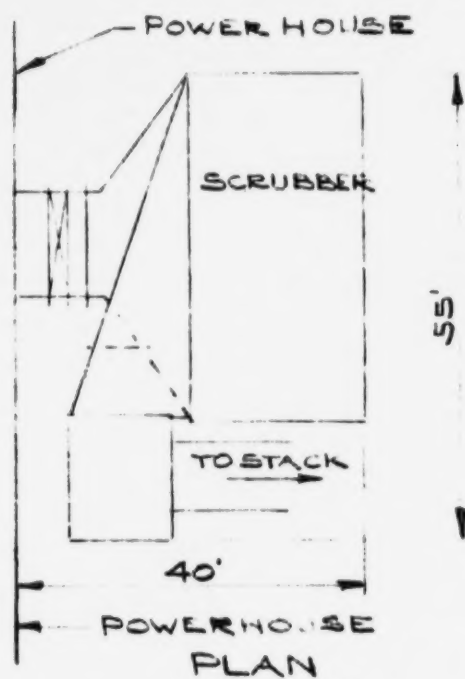


TABLE 1

Space Requirements
Wet Limestone - 167MW

In addition to the equipment shown in Figures 1 & 2, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	167MW	333MW	666MW	1000MW
Limestone Receiving Hopper	15'x 20'	20'x 20'	20'x 30'	30'x 30'
Storage Silo(s)	1-18' dia x 50'	1-25' dia x 50'	2-25' dia x 50'	2-20' dia x 60'
Limestone Grinding Section	35'x 35' x 50'H	40'x 35' x 60'H	40'x 70' x 60'H	50'x 70' x 60'H
Disposal Area - TPY	100,000	200,000	400,000	600,000
" " - Million cu.ft. per year	2	4	3	12
" " - Acre ft. yr.	45	90	130	270

TABLE 2

Space Requirements
Lime Slurry - 167MW

In addition to the equipment shown in Figures 1 & 2, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	167MW	333MW	666MW	1000MW
Lime Storage Silo(s) Assume lime is received in trucks, and can be pneumatically conveyed.	1-16' dia x 50'	1-22' dia x 50'	2-22' dia x 50'	2-26' dia x 60'
Disposal Area - TPY	85,000	170,000	330,000	500,000
" " - Million cu.ft. per yr.	1.5	3	7	10
" " - Acre ft.per yr.	40	75	150	230

TABLE 3

Space Requirements
Magnesium Oxide - 167MW

In addition to the equipment shown in Figures 2 & 3, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	167MW	333MW	666MW	1000MW
Thickeners	1-95'dia	2-95'dia	4-95' dia	4-113'dia
Calcining Area	30'x 200'	30'x 250'	60'x 250'	60'x 300'
Drying Area	40'x 200'	40'x 250'	75'x 250'	75'x 300'
Filter & Centrifuge Bldg.	25'x 25'	25'x 40'	30'x 40'	30'x 50'
Coke Hopper - Truck	15'x 15'	15'x 15'	15'x 15'	15'x 15'
Coke Silo	12'dia x 20'	12'dia x 30'	16'dia x 40'	16'dia x 50'
Misc: MgO receiving, slurring spray tower	25'x 25'	25'x 25'	25'x 25'	25'x 25'
Spray Drying Bldg.	30'x 30'	40'x 40'	50'x 50'	50'x 50'
Acid Plant	75'x 100'	100'x 100'	100'x 125'	100'x 150'
Acid Storage Tanks	2-40'dia x 35'	4-40' dia x 35'	8-40'dia x 35'	12-40'dia x 35'

TABLE 4

Space Requirements
Ammonia Scrubbing - 167MW

In addition to the equipment shown in Figures 4 & 5, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	<u>167MW</u>	<u>333MW</u>	<u>666MW</u>	<u>1000MW</u>
Limestone Hopper	15'x 15'	15'x 15'	15'x 15'	15'x 15'
Limestone Silos	1-18'dia x 50'	1-22'dia x 60'	2-22'dia x 60'	2-24'dia x 70'
Limestone Mill Bldg.	30'x 30'	30'x 30'	30'x 40'	30'x 50'
Bohna Plant	75'x 50'	75'x 70'	75'x 140'	75'x 175'
Acid Plant	75'x 100'	100'x 100'	100'x 125'	100'x 150'
Acidifier/Stripper & Crystallizer Area	30'x 40'	30'x 40'	40'x 40'	40'x 50'
Settling Tank	10'dia	13'dia	18'dia	22'dia
Sulfate Reactor/Settler	10'dia	10'dia	12'dia	12'dia
Acid Storage	2-40'dia x 35'	4-40'dia x 35'	8-40'dia x 45'	12-40'dia x 35'

TABLE 5

Space Requirements
Sodium Scrubbing-Wellman-Lord - 167MW

In addition to the equipment shown in Figures 4 & 5, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	<u>167MW</u>	<u>333MW</u>	<u>666MW</u>	<u>1000MW</u>
Evaporator-Centrifuge Bldg.	50'x 50'	50'x 60'	50'x 75'	50'x 100'
Crystallization Area	50'x 100'	75'x 100'	100'x 100'	100'x 125'
Acid Plant	75'x 100'	100'x 100'	100'x 125'	100'x 150'
Acid Storage	2-40'dia x 35'	4-40'dia x 35'	8-40'dia x 35'	12-40'dia x 35'

TABLE 6

Space Requirements
Sodium Scrubbing-Stone & Webster/Ionics - 167MW

In addition to the equipment shown in Figures 4 & 5, space is required for the following items:

ITEM	SPACE REQUIRED FOR			
	<u>167MW</u>	<u>333MW</u>	<u>666MW</u>	<u>1000MW</u>
Acid Plant	75'x 100'	100'x 100'	100'x 125'	100'x 150'
Regeneration	50'x 50'	50'x 60'	50'x 75'	50'x 100'
Electrolytic Cell Bldg.	50'x 60'	50'x 120'	100'x 120'	100'x 180'
Acid Storage	2-40'dia x 35'	4-40'dia x 35'	8-40'dia x 35'	12-40'dia x 35'

TABLE 7

DATA REQUESTED IN APPLICABILITY STUDY

1. General mode of transportation: truck, rail, barge.
2. Availability of raw materials:
 - a. limestone: distance to supply, mode of transport or delivered cost.
 - b. special sources of hydrated lime, lime, NH_3 , NaOH , Na_2CO_3 .
3. Disposal of waste materials:
 - a. dissolved solids: how much sulfate could be tolerated?
 - b. slurried solids: distance to settling pond?
 - c. dry solids: distance and transport to disposal or cost of disposal?
4. Special local markets for sulfur products: Na_2SO_4 , S, acid, others? Quantify size of market.
5. Availability of utilities:
 - a. clean fuel for reheat or regeneration
 - b. steam, low pressure and high pressure
 - c. power: regular and offpeak
 - d. water: any special problems
6. Required level of control anticipated by the utility.
7. Age of plant - lifetime left - will requirement of control costs shutdown the plant - load factor - reliability factor?
8. Space:
 - a. for scrubber? At what cost?
 - b. for regeneration? distance from plant?

VI. DISCUSSION OF RESULTS

General

The utilities cooperating in this and the previous (1971) study are listed in Section II of this report. Many of the systems studied in 1971 were not revisited this time for one or more of the following reasons: (Note these comments do not apply to the 14 utilities listed in Section II).

- The utility was uncooperative and either could not or would not provide the necessary time and information needed for the study.
- Systems had a very low percentage of units with space available for control units.
- Systems had only a few plants -- systems with a large number of plants were chosen whenever possible to maximize the total capacity surveyed.
- Systems did not have the necessary data readily available such as plot plans, drawings, etc.

In selecting a list of utilities to contact with requests for data, several requirements had to be met, viz.;

- In each study, a maximum of 9 different companies could be approached without approval of the contracting officer; this approval has to be requested in writing including copies of the survey plan and questionnaire forms (Article XV, Contract CPA 70-68). Since approval of the Bureau of Budget is eventually required and usually takes 4-6 weeks minimum, the project officer specified that this not be done since the time involved would delay the results beyond the date needed.

- The data needed for this study generally are not available from smaller utilities since they usually do not have large engineering staffs. Thus larger utilities were indicated as the source of material.
- To achieve a maximum amount of data, utilities with a large number of plants were desirable which again dictated large utilities.
- A sampling from different geographical areas was desired.

In meeting the above requirements, the sampling obtained was by necessity heavily weighted toward large utilities which in turn resulted in a high percentage of large size, relatively new power plants. Thus while about 42 percent of the 1972 generating capacity (basis oil- and coal-fired plants) was studied, only about 15 percent of the number of plants were involved. The results of this study may not, therefore, be truly representative of the entire utility industry but the scope of the task essentially precluded any other approach. Within the limitations imposed by the task "ground rules" the results are valid and should be quite useful in ascertaining the applicability of SO₂-control processes on a retrofit basis.

The specific data that could be quantified from the material collected during the survey are tabulated in Table 8; the Utilities that were surveyed are identified as systems 1 through 10. Each plant within a utility system is identified by an alphabet letter.

Table 8 summarizes the space available for installation of any given process. This information was collected in each Utility's engineering office from plot plans, aerial photographs and interviews with responsible engineers. Particular attention was paid to the availability of space for scrubbers. Area for regeneration was estimated in a less refined manner. The processes which fit were determined by matching the areas for various processes tabulated in Table 9 against those available at the plants.

The complexity factor is a subjective estimate by one of the four investigators on this survey as to the difficulty, i.e., cost, of installing a stack gas cleanup system on the power generating units within a given plant. Since the emphasis primarily was on the scrubber part of a system, the complexity factor mainly reflects the difficulty in installing a scrubber. It was found that the scrubber design is approximately the same for all processes. The complexity factor was estimated to vary from "1", the cost of installation in a new plant ($\approx 25\$/kw$), to "3", which was considered to be the most difficult case ($\approx 75\$/kw$).

Table 8 also contains a summary of plant data and operating characteristics. Units which were investigated range in size from 19-1150 MW, and in age from 0-50 years. Some of the items listed in the table are self-explanatory; the others are discussed below.

Load Factor and Availability

Load factor is defined as the actual power produced during a year divided by the maximum power that could have been produced (based on the unit running continuously for a year at name-plate rating), expressed as a percentage. Availability is defined as the percentage of time during a year that the unit was available for use, whether or not it was actually running.

Load factors varied considerably, but more than half of the reported values are less than 70%. This tends to indicate that for most plants, sufficient steam and power capacity is available the majority of time for use in running a control process. Only during limited peak periods would power and steam be generally unavailable, resulting in the need to either purchase power or reduce plant capacity in order to satisfy the demands of the control process.

Information on availability was difficult to obtain. From the values reported, however, availability seems to be maintained at a high level.

Complexity Factor

In evaluating the applicability of SO₂-control processes to existing power plants, some indication of cost was desirable but specific cost estimates obviously were beyond the scope of the task. It was decided, therefore, to determine qualitatively, to the extent possible, the effort required to install a control unit. Items to be considered included space availability, site accessibility and degree of modification required to the site, buildings, structures and equipment.

In order to reduce the above variables to a common basis, it was decided to refer the cost of all retrofits to that of a new installation by means of a multiplying factor. Further, this factor is always greater than one since a retrofit will undoubtedly cost more than a new installation. On this basis, a complexity factor has been estimated for each power plant studied where a control unit can be installed.

Since reported costs for installing new wet limestone scrubbing units fall in the range of \$20-25/KW while retrofits can cost as much as \$60-70/KW for very difficult installations, a complexity factor range of 1.0 to 3.0 was selected. Although this range is based on the wet limestone scrubbing process it is assumed to apply also to other systems since the gas scrubbing section is similar for all processes and comprises the largest share of the cost. In essence then, the complexity factor indicates how much more a retrofit will cost compared to an identical installation on a new plant.

To reduce the data to a more useable form, the generating capacity for each complexity factor has been determined and is shown below:

<u>Complexity Factor</u>	<u>Retrofit Generating Capacity, MW</u>	<u>*Percent</u>	<u>*Cumulative Percent</u>
1.0	1,037	1.17	1.17
1.5	26,853	30.34	31.51
2.0	9,333	10.54	42.05
2.5	16,012	18.10	60.15
3.0	16,477	18.61	78.76
	<u>69,712</u>	<u>78.76</u>	

*Based on total capacity surveyed -- 88,520 MW

The above results show that based on the criteria established for this evaluation, about 42% of the generating capacity studied can be retrofitted with SO₂-control units at a complexity factor of 2.0 (~\$50/kw) or less. The data are presented graphically in Figure 6.

An independent statistical evaluation of the complexity factors has been made by EPA and a copy of the results of their evaluation is shown in Appendix A of this report.

Power Costs

In addition to the data on the capital investment required for installing SO₂-control units, information on increases in power production costs is also needed. To provide an indication of this increase the complexity factor was divided by the load factor, thus converting relative capital investments to costs per unit of power production. Since capital charges generally comprise more than half of the total operating costs of a control unit, the incremental cost of producing power will be approximately proportional to incremental investment. The results of this operation are shown graphically in Figure 7 as a function of generating capacity. From Figure 7 it is seen that about 50% of the generating capacity studied could be retrofitted at relative incremental unit power costs of 3.5 or less which corresponds to an actual incremental power cost of about 2.0 mills/kwh, based on capital costs only. Other costs will add an additional 0.5-1.5 mills/kwh so that the total incremental power costs become 2.5-3.5 mills/kwh.

The actual incremental power costs were calculated using the following assumptions:

- Annual capital charges (cost of money, depreciation, etc.) and maintenance costs will equal 20% of investment.
- A complexity factor of 1.0 (i.e., new plant) is equivalent to a \$25/kw investment.

The following example illustrates the calculation involved:

Complexity Factor = 1.0; Invest = \$25/kw; Load Factor = 0.5

$$25 \frac{\$}{\text{kw}} \times 0.2 \frac{\$}{(\$)(\text{yr})} \times 1000 \frac{\text{mills}}{\$} \times \frac{\text{yr}}{8760 \text{ hrs}} \times \frac{1}{0.5} = 1.14 \frac{\text{mills}}{\text{kwh}}$$

Thus a complexity factor/load factor (CF/LF) ratio of 2.0 (i.e., 1.0/0.5) results in a unit cost of 1.14 mills/kwh based on capital costs only; total costs would be 0.5-1.5 mills greater than this value. Note that the CF/LF ratio is independent of the actual values of each; that is, a complexity factor of 2 and a load factor of 0.5 produces the same results as does a combination of 4 and 1 for complexity and load factors respectively.

The above information is valid for general use but it should not be used for specific cases since no two power plants will have the same distribution of operating costs. Exact costs for a specific case can be determined only by using the pertinent factors that apply to that installation. The information presented herein is felt to be valuable, however, in that it shows approximate ranges of incremental costs that will result from installing SO₂-control units on power plants.

FIGURE 6
RELATIVE INSTALLED COST OF
RETROFIT SO_2 - CONTROL UNITS
DISTRIBUTION OVER GENERATING CAPACITY

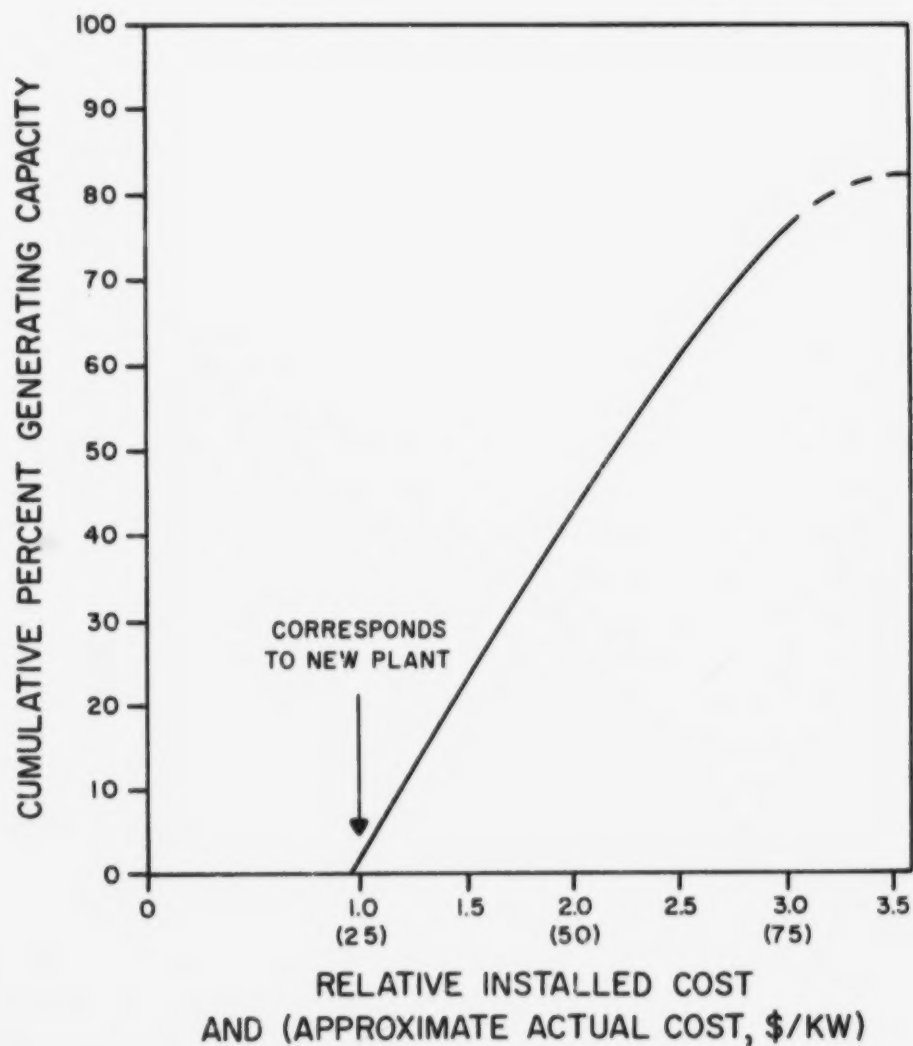
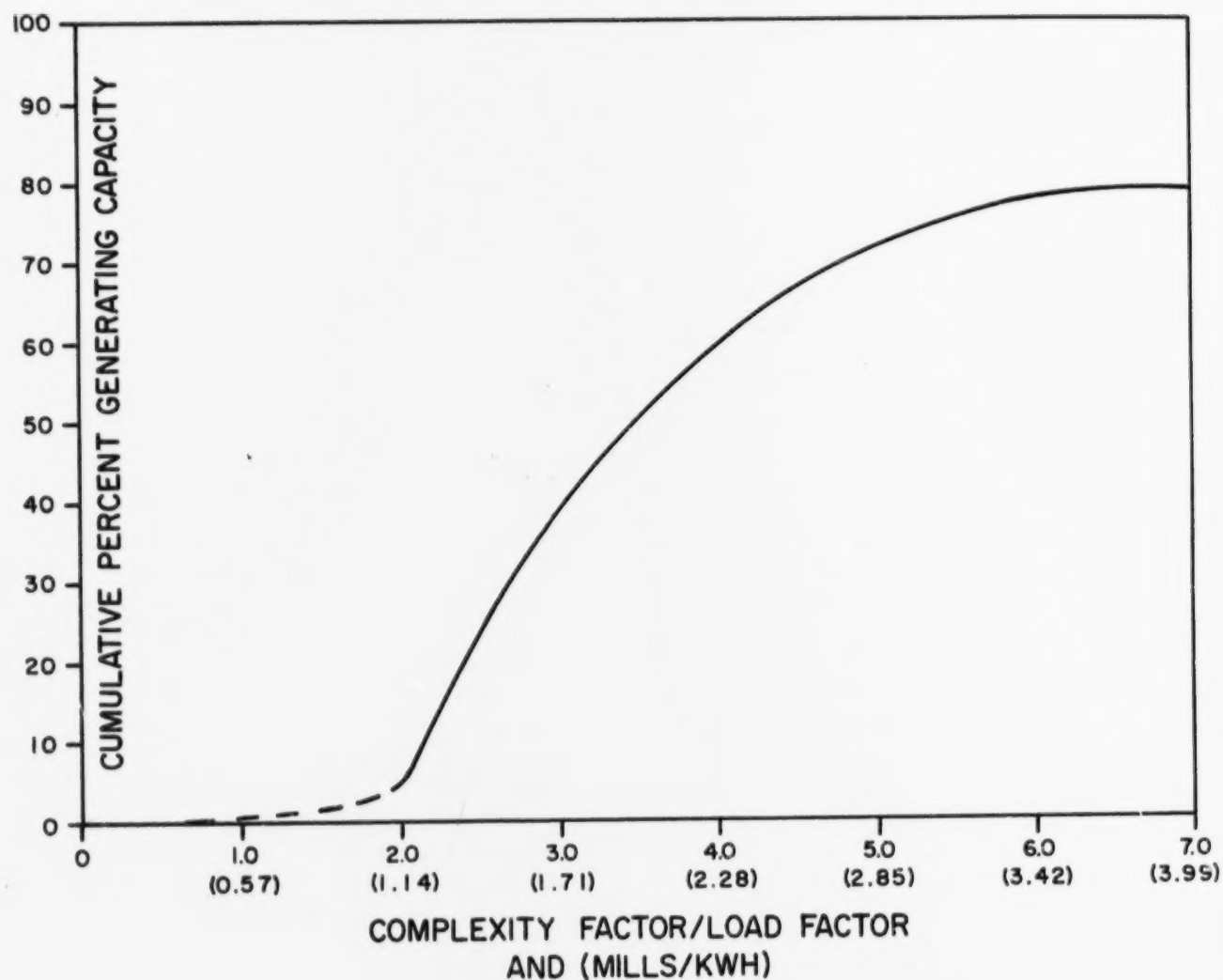


FIGURE 7
RELATIVE CONTRUBITION OF CAPITAL COST TO
INCREMENTAL ANNUALIZED UNIT PRODUCTION COST
DISTRIBUTION OVER GENERATING CAPACITY



Method of Transportation

Fuel is delivered to power plants by a variety of methods, including truck, rail, barge, tanker, pipeline, and conveyor. In general, receiving facilities are adequate to handle shipments of raw materials needed for a control process and represent no hindrance to the installation of such a process.

Power plants located in urban or highly-populated areas commonly have little available outside area for bulk storage of raw materials. However, since many of these plants are coal-to-oil conversions, the storage areas and handling facilities (reclaimers, conveyors, etc.) originally used for coal could be used for raw materials. Plants in suburban or rural areas usually have adequate open area readily available for these purposes.

Disposal of Waste Materials

The two most common methods used for disposal of ash are:

- 1) Sluicing to settling pond.
- 2) Transfer to intermediate holdup area (pond, silo, etc.) from which the ash is hauled to off-site disposal by contractor.

The first method is commonly employed at power plants in rural areas, where space availability is not restricted. The latter method is frequently used at urban sites, where space is at a premium.

Non-regenerative control processes produce large quantities of solid waste materials. Plants which now contract for ash

disposal could dispose of process wastes similarly. Plants with adequate pond area could possibly use this for process waste disposal, but potential water pollution problems caused by seepage of soluble salts (particularly sulfates) into the water table or by discharge of pond effluent to nearby rivers or streams could restrict their use.

Water quality standards vary not only from state to state, but also within a state, depending upon the specific body of water being considered. In most cases, the standards have not been defined in detail and limits on dissolved solids, especially sulfates, have not been set. This makes it difficult to determine whether or not ponding would be a permissible disposal method. Virtually all standards restrict completely the dumping of solids into streams, rivers, etc., and direct discharge of solids wastes cannot be considered.

Clean Fuel Availability

In virtually all cases, a clean fuel (i.e., a "0" S fuel) of some type is available for use in the control process. However, natural gas is generally not available at reasonable cost during the winter months, when the demand is great for use in home heating. As a result, those plants which indicated only natural gas as an available clean fuel would have to stockpile gas during the summer months, purchase gas at premiums rates during the winter months, or develop a source of supply for other types of clean fuel.

Possible Plant Shutdowns

In only one case did a utility indicate a definite plant shutdown if controls were imposed. However, this should not be taken to mean that control processes would be installed on all other plants to curtail SO₂ emissions. Rather, many

companies stated that plants would be converted to low-sulfur fuels, if available. Several plants have already been converted and have long-term commitments for low-sulfur fuel, although what is meant by "long-term" is not clear.

Some items were identified and investigated during the survey but could not be quantified for inclusion in Table 8.

These are discussed separately under the individual item headings.

Availability of Utilities

The power companies have not investigated the problem of supplying steam, power or water to an air pollution control system. Therefore, quantification of these items is not possible but some of the aspects of supplying these can be discussed.

Steam and power, of course, are produced in the power plants and are available in just about any quantity desired. A penalty occurs because the steam or power used decreases the plant power output. The amount of power that can be taken from a particular plant must be evaluated on a system basis considering the power available at peak loads from other plants and even other grids. It is unlikely that all plants in a system will install pollution control equipment simultaneously; also the process of installing it will last several years. If this is the case, the Utility can factor the increased demand for in-plant power into the planned growth rate of power production for the Utility as a whole.

At the present time the natural source of cooling water and process water to Utilities does not appear to be limited. However, water treatment facilities will have to be added to accommodate any sizeable increase in water flow over present quantities. Also, the presently ill-defined thermal pollution standards and cooling water effluent standards will have to be complied with.

Required Level of Pollution Control
Anticipated by Utility

At the time of the survey the required level of pollution control was in a state of flux. Negotiations were at a high level of activity between the Utilities and the State pollution control organizations. Some aspects of the situation can be discussed.

In presenting their case as to what is presently technically feasible, the Utilities are expressing a willingness to use, or in many cases are already in the process of utilizing, low-sulfur fuel (generally oil), 99.9+% efficient electrostatic precipitators and 800-1000 ft. stacks. The State organizations, in maneuvering to minimize the impact of the power plants on the total environment, have expressed the position, directly or indirectly, that air pollution cannot be reduced at the expense of increasing water pollution. The controls for the immediate future will come out of these discussions.

If the States determine that the immediately available technology will not meet the local environmental requirements, then Utilities are faced with adapting new technology to power generation to meet future pollution laws. This is superimposed on the vast power plant expansion now in progress. Nearly all utilities have more power production on the drawing boards or in construction than they have in operation. The new plants have provisions for pollution control which will probably be state-of-art at the time of construction. The argument that appears to come through in discussions with the Utilities is that the increase in power production is their prime goal, economically and socially, and they don't feel this can be done with unproven equipment. Present scrubber technology is placed in this category and they fear that large scale utilization of scrubbers would jeopardize not only future but present power

producing capacity. Coal gasification, either pipeline gas or onsite low-Btu gas, is looked upon as a competitor to scrubbing. Also, the utilities seem open to new techniques for burning coal. Future pollution controls will depend as much on the vagaries of technological development as on any discussion that can presently be held.

Availability of Raw Materials

Most of the utilities contacted during this study could furnish no information on raw materials availability, potential suppliers, distance to source of supply, or cost unless they had considered a particular process for a prototype installation or for planning purposes. This type of information is difficult to get for a particular power plant site and would require considerable effort, beyond the scope of this study, to obtain.

In general, raw material availability should not be a problem. The absorbent materials used in the typical processes considered are:

- Limestone
- Lime (or hydrated lime)
- Magnesium oxide
- Ammonia
- Caustic (sodium hydroxide)
- Soda ash (sodium carbonate)

These are common chemicals which are produced in substantial quantities and should be readily obtainable in most areas where they might be needed by power plants. For example, results of one recent study (Availability of Limestones and Dolomites, Task #1 Final Report, Contract No. CPA 70-68) prepared for EPA by the M. W. Kellogg Company show that limestone is generally available throughout the U.S. but in some locations transportation costs will be high, as discussed below.

In addition, materials which would otherwise be considered as waste products could be used as absorbents, e.g., calcium carbide sludge. In some cases, the raw materials, although available, could be costly.

This is the case, for example, for limestone in the Northeast. For many plants in this area, particularly for coastal plants, an adequate source of limestone is not nearby, and transportation charges could greatly increase the cost of this material to utilities.

Potential Markets for Sulfur Products

A variety of products can be recovered from SO₂-control processes, primarily elemental sulfur, sulfuric acid, and liquid sulfur dioxide. Other products, chiefly sulfites and sulfates, can also be obtained. Most of the utilities surveyed had little or no information on potential markets for any of these products. This information could best be obtained by a market study for each plant.

From discussions with the utility companies, some generalizations can be made. The composition and purity of products from control processes is not normally known. Consequently, their compatibility with specifications for raw materials of potential users cannot be determined. In other words, it is not known whether these materials would be salable. Also, the willingness of potential users to switch from normal raw material suppliers to power plants as a source is questionable.

Markets must be nearby, within about 50 miles. Utilities could not afford to ship products any considerable distance. Power companies generally do not want to get into the chemical business and would therefore prefer to sell all of the product to a single user through long-term contract if possible. Otherwise they might have to set up a sales and marketing organization.

In investigating a potential market, consideration must be given to the amount of material produced. If power plants

installed control processes on a large scale, it may well be that the additional quantities of sulfur products would glut the market. For example, converting the estimated SO₂ emissions from all U. S. power plants in 1969 to an equivalent amount of sulfuric acid would approximately double the supply of acid. Although it is unlikely that this type of situation would occur on such a large scale, it is quite possible for it to happen in small areas.

TABLE 8

SUMMARY OF POWER PLANT DATA

System 1
MWe 5950

Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	AREA AVAILABILITY				Clean Fuel Avail.	Complexity Factor
					Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal Area	Method		
A/400	2-110	21	^b Coal 15% Ash 1% S	94/98	10,000	Unlimited	5 yrs	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	1-180	14		92/93	5,000	@ 2500				2.5
B/2204	2-400	7	^b Coal 15% Ash 1% S	93/93	30,000	Unlimited	7 yrs	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	2-702	3		107/75	40,000	@ 2500				2.5
C/330	2-82	23	^b Coal 15% Ash 1% S	85/95	10,000	Unlimited	7 yrs	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	1-170	17		94/93	5,000	@ 2500				2.5
D/410	3-40	30	^b Coal 15% Ash 1% S	74/83	15,000	Unlimited	5 yrs	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	2-145	19		90/96	10,000	@ 2500				3.0
E/791	2-40	32	^b Coal 15% Ash 1% S	80/95	10,000	Unlimited	10 yrs	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	2-70	24		90/98	10,000	@ 2500				2.5
	1-571	0		---	15,000					1.5

TABLE 8

SUMMARY OF POWER PLANT DATA

System 1
MWe 5950

Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	AREA AVAILABILITY				Clean Fuel Avail.	Complexity Factor
						Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal	Area	Dist.	Method	
F/1285	2-180	15	Coal ⁴ 15% Ash	95/95	10,000	Unlimited	10 yrs	NA	Sluice	Dump Nat. Gas #2 Pipe- line	2.5
	2-305	12	1% S	93/93	16,000	@ 2500					2.5
	1-315	11		97/90	10,000						2.5
G/530	2-115	20	Coal ⁴ 15% Ash	88/89	10,000	Unlimited	5 yrs	NA	Sluice	Dump Nat. Gas #2 Pipe- line	2.0
	2-150	18	1% S	95/90	10,000	@ 2500					2.0

System
MWe

2

4289

SUMMARY OF POWER PLANT DATA

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal			Clean Fuel Avail.	Complexity Factor
							Area	Dist.	Method		
A/229	1-87	27	Coal ⁶ 7-25% Ash 4% S	43/NA	5,000	Unlimited @ 2500	127 acre	3 mi	Truck to Dump	#2 @ 90¢/ MMBtu	2.5
	1-142				5,000						2.5
⁵ B-480	2-90	22	Coal ⁶ 7-25% Ash 4% S	64/NA	10,000	40,000 @ 1500	83 acre	3 mi	Truck to Dump	#2 @ 90¢/MMBtu	3.0
	1-300				10,000						3.0
⁵ C-360	2-180	13	Coal ⁷ 7-25% Ash 4% S	68/NA	20,000	80,000 @ 2000	216 acres	3 mi	Truck to Dump	#2 @ 90¢/MMBtu	2.5
	1-80	20	Coal ⁸ 7-25% Ash 4% S	75/NA	5,000	Unlimited @ 2500	200 acres	3 mi	Truck to Dump	#2 @ 90¢/MMBtu	2.5
⁵ D-225	1-80	20	Coal ⁸ 7-25% Ash 4% S	75/NA	5,000	Unlimited @ 2500	200 acres	3 mi	Truck to Dump	#2 @ 90¢/MMBtu	2.5
	1-145				5,000						2.5

SUMMARY OF POWER PLANT DATA

System 2
MWe 4289

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration		Waste Disposal		Clean Fuel Avail.	Complexity Factor
						Dist. From Scrubber, ft	Area	Dist.	Method		
E-245	1-59	22	Coal ⁶ 7-25% Ash 4%S	67/NA	5,000	Unlimited @ 2500	NA	<1 mi	Sluice to pond	#2 @, 90¢/MMBtu	2.5
	1-186				5,000						2.5
F-1100	2-550	4	Coal ⁶ 7-25% Ash 4%S	72/NA	20,000	Unlimited @ 2500	NA	NA	Truck to Dump	#2 @ 90¢/MMBtu	2.5
G-1650	3-550	2	Coal ⁶ 7-25% Ash 4%S	68/NA	45,000	40,000 @ 1500	223 acres	3 mi	Truck to Dump	#2 @ 90¢/MMBtu	3.0

SUMMARY OF POWER PLANT DATA

System 3

MWe 2458

AREA AVAILABILITY										
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		Clean Fuel Avail.	Complexity Factor
							Area	Dist. Method		
A-531	1-531	1	Coal ⁴ 12.7% Ash 2.3%S	NA	Unlimited	135,000 @ 600	265 acres	adj. Sluice	#2 oil 82¢/MMBtu	1.5
B-886	4-100		Coal ⁴ 9.8% Ash 2.5%S	68/79	None	Unlimited @ 1300	59 acres	2000 feet Sluice	#2 oil 82¢/MMBtu	---
	1-125	18-21		79/NA	None					---
	1-361			61/NA	80,000					1.5
C-640	4-160	11- 14	Coal ⁹ 9.8% Ash 3.3%S	68/81	None	---	45 acres	adj. Sluice	#2 oil 82¢/MMBtu	---

SUMMARY OF POWER PLANT DATA

System 4
MWe 6620

AREA AVAILABILITY										
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		Clean Fuel Avail.	Complexity Factor
							Area	Dist. Method		
A-1932	2-176	18	Coal & Gas	62/NA	6,000	195,000 @ 1400	462 acres	5 mi	Trucked by Contractor Offsite	#6-LO S Oil
	2-180	18	Coal & Gas	62/NA						
	1-336	12	Coal & Gas	85/NA	15,400					
	1-346	12	Coal & Gas	85/NA						
	1-538	3	Coal	90/NA	5,000					
B-908	1-284	16	Coal & Gas	85/NA	None	600,000 @ 1500	60 acres	10 mi	Trucked by Contractor Offsite	#6-LO S Oil
	1-275	16	Coal & Gas	85/NA	None					#2 Oil @ 82¢/ MMBtu
	1-349	14	Coal & Gas	85/NA	2400					3.0

6620

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal			Clean Fuel Avail.	Complexity Factor
							Area	Dist.	Method		
C-1143	6-50	48	Coal ⁴ 12% Ash 2.9% S	NA	None	105,000 @ 2100	60 acres	5 mi	Trucked by Contractor Offsite	#6-LO S Oil	--
	1-145	21		60/NA	None					#2 Oil @ 82¢/ MMBtu	--
	1-126	21		60/NA	None						--
	1-542	4		90/NA	20,000						2.5
D-1622	2-811	1	Coal ⁴ 13.7% Ash 4% S	90/NA	60,000	Unlimited	25 years	1.5mi	Sluice	#6-Lo S Oil #2 Oil @ 82¢/ MMBtu	1.5

SUMMARY OF POWER PLANT DATA

System 5
MWe 7419

Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	AREA AVAILABILITY				Clean Fuel Avail.	Complexity Factor
					Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Area	Waste Disposal Dist. Method		
A-800	3-100	18	Coal ⁴ 15%Ash 3%S	NA	18,000	Unlimited @ 2500	NA	Sluice to Pond	#2 90¢/MMBtu	2.5
	1-500				20,000					2.0
¹⁰ B-240	4-60	24- 42	Coal ⁴ 15%Ash 3%S	NA	None		NA	Sluice to Pond	#2 90¢/MMBtu	0 ¹³
² C-1539 -49-	1-250	7	Coal ⁴ 15%Ash 3%S	NA	6,500	200,000 @ 2000	NA	Sluice to Pond	#2 90¢/MMBtu	2.5
	1-319	5			8,000					2.5
	1-481	4			12,500					2.5
	1-490	3			12,500					2.5
D-490	2-245	9	Coal ⁴ 15%Ash 3%S	NA	12,500	120,000 @ 2000	NA	Sluice to Pond	#2 90¢/MMBtu	1.5

System

5

ME

7419

SUMMARY OF POWER PLANT DATA

AREA AVAILABILITY									
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration		Waste Disposal	
						Area, ft ²	Dist. From Scrubber, ft	Area	Dist. Method
E-1250	3-100	22	Coal ⁺ 15%Ash 3%S	NA	20,000	Unlimited @ 2500	NA	NA	Sluice to pond
	2-125	15							
	2-350	0							
F-3100	2-700	1	Coal ⁺ 15%Ash 3%S	NA	45,000	Unlimited @ 2500	NA	NA	Sluice to pond
	2-850	0			45,000				

SUMMARY OF POWER PLANT DATA

System 6
MWe 13891

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal			¹⁵ Clean Fuel Avail.	Complexity Factor
							Area	Dist.	Method		
A-1980	5-141	20	Coal ⁷	55/NA	} Roof Mount	87,500 @ 150	270 acre	600 feet	Sluice	.	3.0
	1-150	20									
	1-550	8			} 20,000					1.5	
	1-575	11									1.5
B-1396	2-200	17	Coal ¹¹	56/NA	} 80,000	Unlimited @ 1700	495 acres	1200 feet	Sluice		2.0
	2-223	17									
	1-550				40,000						2.0
C-823	1-223	17	Coal ⁴	57/NA	} 80,000	490,000 @ 1400	166 acres	800 feet	Sluice	.	1.5
	3-200	16									
D-1700 ⁵	4-175	18	Coal ⁸	64/NA	} 30,000	72,000 @ 1000	335 acres	400 feet	Sluice		1.5
	5-200	17									

SUMMARY OF POWER PLANT DATA

System

6

MWe

13891

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		15 Clean Fuel Avail.	Complexity Factor	
							Area	Dist. Method			
E-1486	4-125	20- 21	Coal ¹	52/NA	Roof Mount	700,000 @ 2000	211 acres	2400	Sluice	.	3
	2-147	19- 20			Roof Mount					.	3
	4-173	13- 14									3
F-1256	2-300	16	Coal ⁴	64/NA	10,000	270,000 @ 1000	473 acres	1500	Sluice		2
	2-328	13			10,000						2
G-950	1-950	7	Coal ⁴	63/NA	30,000	210,000 @ 1500	157 acres	1600	Sluice		1.5

SUMMARY OF POWER PLANT DATA

System 6
MWe 13891

AREA AVAILABILITY										
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		¹⁵ Clean Fuel Avail.	Complexity Factor
							Area	Dist. Method		
H/1750	10-175	16- 19	Coal ¹⁴	71/NA	180,000	600,000 @ 1500	145 acres	2400 feet	Sluice	1.5
⁵ J-2550	2-700	9	Coal ¹⁶	61/NA	50,000	100,000 @ 900	386 acres	1000 feet	Sluice	1.5
	1-1150				40,000	100,000 @ 700				1.5

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System

7

MW

9678

SUMMARY OF POWER PLANT DATA

Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	AREA AVAILABILITY				Clean Fuel Avail.	Complexity Factor
					Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal Area	Dist. Method		
A-572	1-198	19	Coal ⁹	87/NA	3000	200,000 @ 1000	NA	Contractor Offsite	Nat. Gas #2 Oil 80-100¢/ MMBtu	3.0
	1-374	13		87/NA	Unlimited					2.0
B-2087	4-75	NA	Coal ⁹	NA	None	100,000 @ 600	NA	Contractor; Land Fill		--
	1-107	18		52/NA	None					--
	1-360	12		64/NA	None					--
	2-660	7		70/NA	45,000					1.5
C-1232	2-616	4	Coal ¹⁷	45/NA	Unlimited	240,000 @ 500	10 years	Land Fill		1.5
D-1120	2-55	28	Coal ⁴	30/NA	None	350,000 @ 1500	NA	Contractor or Offsite		--
	2-105	26		40/NA	None					--
	1-800	1		NA	20,000					3.0

System

7

MWe

9678

SUMMARY OF POWER PLANT DATA

AREA AVAILABILITY										
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		Clean Fuel Avail.	Complexity Factor
							Area	Dist. Method		
E-692	4-173	17- 20	Oil ⁹	56-65/NA	27,500	180,000 @ 900	NA	Contractor Offsite		2.0
F-1042	5-48	NA	Coal ⁴	32/NA	None	110,000 @ 400	~0	Contractor		--
	1-121	NA		64/NA	None					--
	1-326	14		75/NA	Unlimited					2.5
	1-355	9		71/NA	Unlimited					2.5
G-1269	1-188	17	Coal ⁹	62/NA	Has Scrubber	200,000 @ 1400	NA	Contractor		--
	1-184	17		54/NA	4500					3.0
	1-299	15		78/NA	5000					3.0
	1-598	8		61/NA	16,000					3.0

System

7

MWe

9678

SUMMARY OF POWER PLANT DATA

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	Scrubber Area, ft ²	Regeneration	Waste Disposal			Clean Fuel Avail.	Complexity Factor
						Dist. From Scrubber, ft	Area	Dist.	Method		
H-980	1-225	24	Coal ⁴	39/NA	None	60,000 @ 500	0		Contract or Offsite	.	---
	1-170	23		65/NA	None	62,000				.	---
	1-225	16		76/NA	4000						3.0
	1-360	10		NA	None						---
⁵ J-684 1561	1-99	44	Gas ⁹	14/NA	} 30,000	50,000 @ 400	NA		Contract or Offsite		---
	1-225	14	Coal	57/NA							2.5
	1-360	11	Coal	63/NA							2.0

SUMMARY OF POWER PLANT DATA

System 8
MWe 6251

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal			Clean Fuel Avail.	Complexity Factor
							Area	Dist.	Method		
A/1650	4-125	21- 24	Oil ¹⁹	55/90	29,000		0.25 years	1300 feet	Contrac- tor Offsite	Nat. Gas.	2.5
	1-350	10			13,500	400,000 @ 1200				.	2.0
	2-400				22,000						1.0
B-653	2-327	11	Coal ⁹	75/78	46,000	190,000 @ 1500	1.5 years	1200 feet	Contrac- tor Offsite	Nat. Gas #2 Oil	1.5
C-599	1-300	15	Oil ¹⁸	75/91	25,000		0	--	None Offsite	Nat. Gas #2 Oil	2.0
	1-219			75/80		180,000 @ 800					2.0
		1-80	0		---	50,000					

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System

8

MWe

6251

SUMMARY OF POWER PLANT DATA

AREA AVAILABILITY											
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ²		Waste Disposal		Clean Fuel Avail.	Complexity Factor
						Dist. From Scrubber, ft	Area	Dist.	Method		
D-619	2-148	20	Oil ⁹	57/86	12,500	94,000 @ 450	0	--	Contractor Offsite	Nat. Gas #2 Oil	2.0
E-1115	1-425 1-690	4	Oil, Coal	80/80	8,500 11,000	170,000 @ 1000	0.4 years	1400 feet	Contractor Offsite	Nat. Gas	2.5 1.5
F-503	2-140 1-223	30 17	Oil ⁹	50/81	40,000	100,000 @ 600	1.2 years	1400 feet	Contractor Offsite	None	2.5 2.5
G-650	2-325	13	Oil ¹⁸	75/75	20,000	200,000 @ 400	1.3 years	700 feet	Contractor Offsite	Nat. Gas	2.0

SUMMARY OF POWER PLANT DATA

System 9
MWe 1990

Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability Percent	AREA AVAILABILITY				Clean Fuel Avail.	Complexity Factor
					Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal Area	Dist. Method		
A-154 ^s	6-22	50	Oil ^{1e}	45/95	9600	@ 180	0	---	#2 Oil	² 3.0
	3-6	30						Contrac- tor Offsite		3.0
B-760 ^s	2-380	5-7	Oil ^{1e}	69/90	7200	120,000 @ 500	0	---	#2 Oil	3.0
C-1219	3-50	11- 15 0	Oil ^{1e}	75/90	NA	204,000 @ 1200	0	---	#2 Oil	
	2-156			55/90	34,000			Contrac- tor Offsite		3.0
	1-156				Now Installed					---
D-458	3-90	18- 23	Oil ¹²	60/90	20,000	720,000 @ 1500	0	---	#2 Oil	3.0

SUMMARY OF POWER PLANT DATA

System 10
MWe 2718

AREA AVAILABILITY									
Plant/ Size MW	Unit Size MW	Age Yrs	Fuel	Load Factor/ Availability, Percent	Scrubber Area, ft ²	Regeneration Area, ft ² Dist. From Scrubber, ft	Waste Disposal		
							Area	Dist. Method	Clean Fuel Avail.
A-2175	2-175	10	Coal ¹⁷ 22% Ash .65% S	88/NA	} 75,000 135,000	Unlimited @ 1,000	1048 acres	2 mi Sluice	Nat. Gas 40¢/MMBtu
	3-225	8		88/NA					2.5
	2-800	1.5		74/NA					2.5 3.0
B-115	1-115	10	Coal ¹⁴ 9% Ash .5% S	95/NA	15,000	30,000 @ 100	240 acres	1 mi Sluice	Nat. Gas 60¢/MMBtu
C-230	2-115	12	Gas ³ or Oil 1% S	43/NA	90,000	100,000 @ 500	160 acres	NA	Nat. Gas 40¢/MMBtu
D-198	2-99	17	Gas ³ or Oil	35/NA	20,000	Unlimited @ 600	Unlimited	NA	Nat. Gas 40¢/MMBtu
									2.0

FOOTNOTES

1. Excludes small units and those being retired.
2. Controls may shut down Plant A.
3. Truck, Rail and pipeline transportation available.
4. Rail transportation available.
5. Cannot accommodate process #3.
6. Truck and barge transportation available.
7. Truck, rail and barge transportation available.
8. Truck and rail transportation available.
9. Barge transportation available.
10. Cannot accommodate any process.
11. Rail and barge transportation available.
12. Tanker transportation available.
13. Controls will shut down plant.
14. Information not available but availability believed to be high.
15. Information not available but clean fuel believed to be generally unavailable.
16. Truck transportation available.
17. Conveyor from mine mough.
18. Pipeline transportation available.
19. Barge and pipeline transportation available.

TABLE 9

REGENERATION PROCESS AREAS*
(FT²)

No. of Scrubbers	Approx. MW	(1) Limestone	(2) Lime	(3) MgO	(4) NH ₃	(5) W-L	(6) SW/I
1	167	3,100	1,300	45,800	21,200	21,300	18,700
2	333	5,000	2,500	66,900	29,300	28,900	28,000
3	500	6,900	3,800	88,000	37,300	36,400	37,400
4	667	8,900	5,000	109,200	45,400	44,000	46,700
5	835	10,800	6,300	130,300	53,400	51,500	56,100
6	1000	12,700	7,500	151,400	61,500	59,100	65,400

One scrubber is needed for each 167 MW

*Areas are derived from Tabulations listed in Section IV --
Basis of Evaluation.

Process

- (1) Limestone slurry scrubbing.
- (2) Lime slurry scrubbing.
- (3) Magnesium oxide scrubbing with regeneration.
- (4) Ammonia scrubbing -- Bohna regeneration
- (5) Sodium scrubbing -- Wellman-Lord (Wellman-Power Gas, Inc.)
- (6) Sodium scrubbing -- Stone and Webster/Ionics

APPENDIX A

EPA STATISTICAL ANALYSIS OF KELLOGG APPLICABILITY SURVEY

The Kellogg data have been evaluated to determine the representativeness of the sample and to determine trends in the magnitude of the complexity factor. The survey sample is heavily weighed toward the larger, newer plants. Boiler unit size is strongly correlated with unit age. There is good evidence that newer, larger units are easier to retrofit than older, smaller units.

Mitre Corporation has prepared a distribution of new and existing power plants over size and age from FPC data. The plant size distribution for existing (1970) coal and oil-fired utilities is compared to the Kellogg sample in Figure 1. Kellogg covered essentially all of the plant capacity over 1000 MW but only 6% of that under 400 MW. 60% of the plants in the Kellogg sample are larger than 1200 MW, but 50% of the actual plants are larger than 700 MW.

Figure 2 illustrates the distribution of complexity factor versus number of units (not plants) for six combinations of age and size intervals. The data presented include 90% of the units surveyed by Kellogg. Essentially all of the units over 500 MW were built in the last ten years. Most of the surveyed units under 100 MW are over 20 years old. Very few units were surveyed in the following blocks:

- 1) 0-99 MW, 0-19 years
- 2) 100-199 MW, 0-9 years
- 3) 200-499 MW, 20 + years
- 4) 500 + MW, 10 + years

There are very few existing, large, but old units as in blocks 3 and 4, but the Kellogg trend of looking at large systems and plants probably prevented a representative sample of existing,

small, but new units as in blocks 1 and 2. These units would be more prevalent in smaller systems and plants. The block covering 200-499, 0-9 years has a smaller sample size than any other of the blocks presented, and its results are questionable.

There appears to be strong trends of complexity factor with unit size and age as illustrated in this summary table:

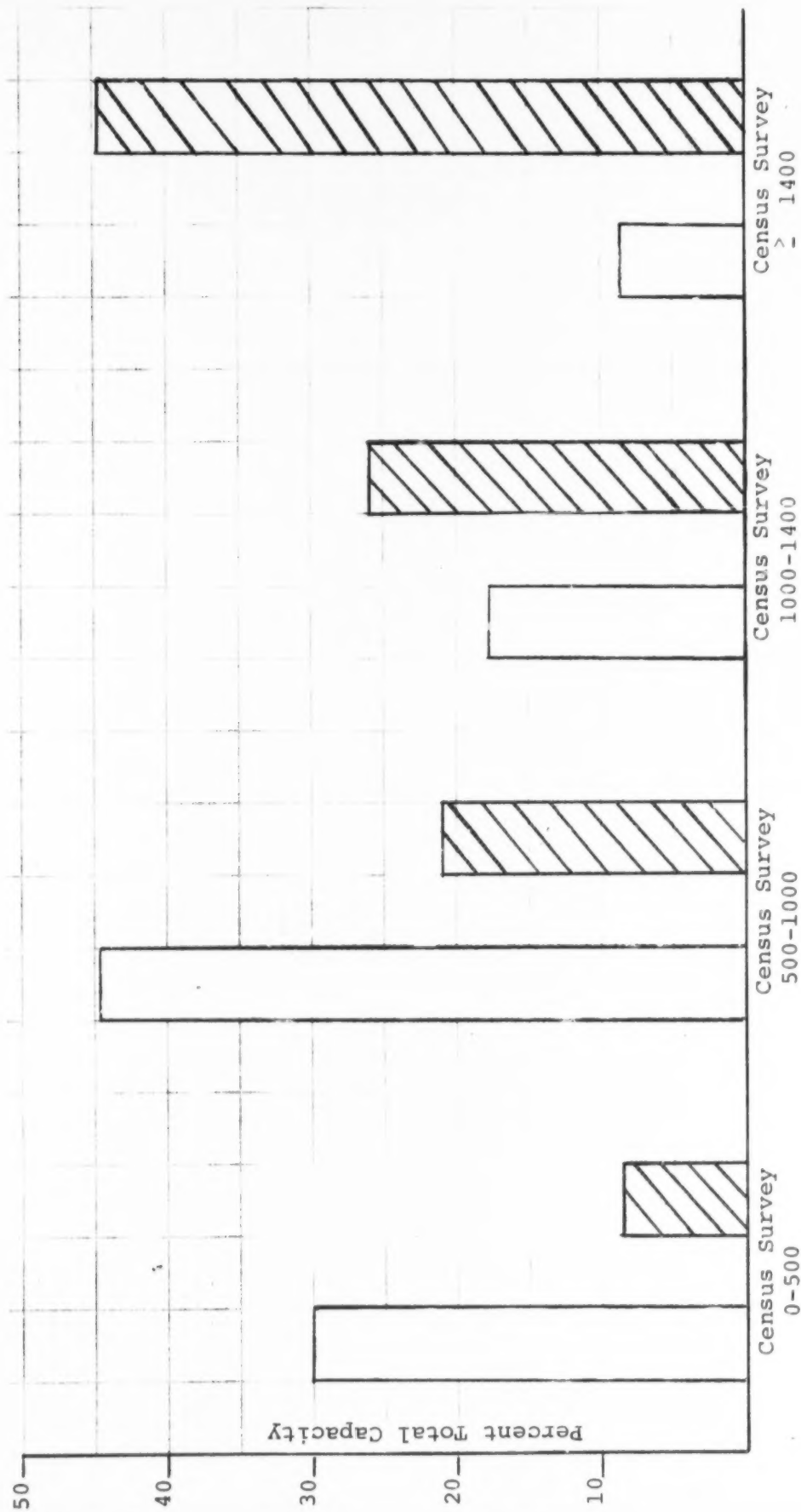
Table 2: Average Block Complexity Factors
Age (Years)

	0-9	10-19	20 +
0-99	-	-	3.05
size (MW) 100-199	-	2.37	2.79
200-499	2.32	2.16	-
500 +	2.05	-	-

Age appears to be most important in older units and size in younger units, though differentiation of age and size is very difficult since they correlate so well for this sample. More data on the newer, smaller units would permit a better understanding of size effects on complexity factor.

Evaluation of the complexity factor was done on unit size and age, not plant size and age. We have no readily available distribution of actual boiler units on the basis of unit size and age. However, the Kellogg sample will probably be more representative on the basis of unit data than on the basis of plant data. Nevertheless, the distribution of complexity factors over actual boiler unit population will not be the same as Kellogg's distribution and all-inclusive conclusions should await an analysis on the basis of actual unit data on size and age.

Figure 1: Distribution of Sample Over Plant Size
 Mitre Census and Kellogg Survey
 Total Mitre Census MW = 264,715
 Total Kellogg Survey MW = 56,571



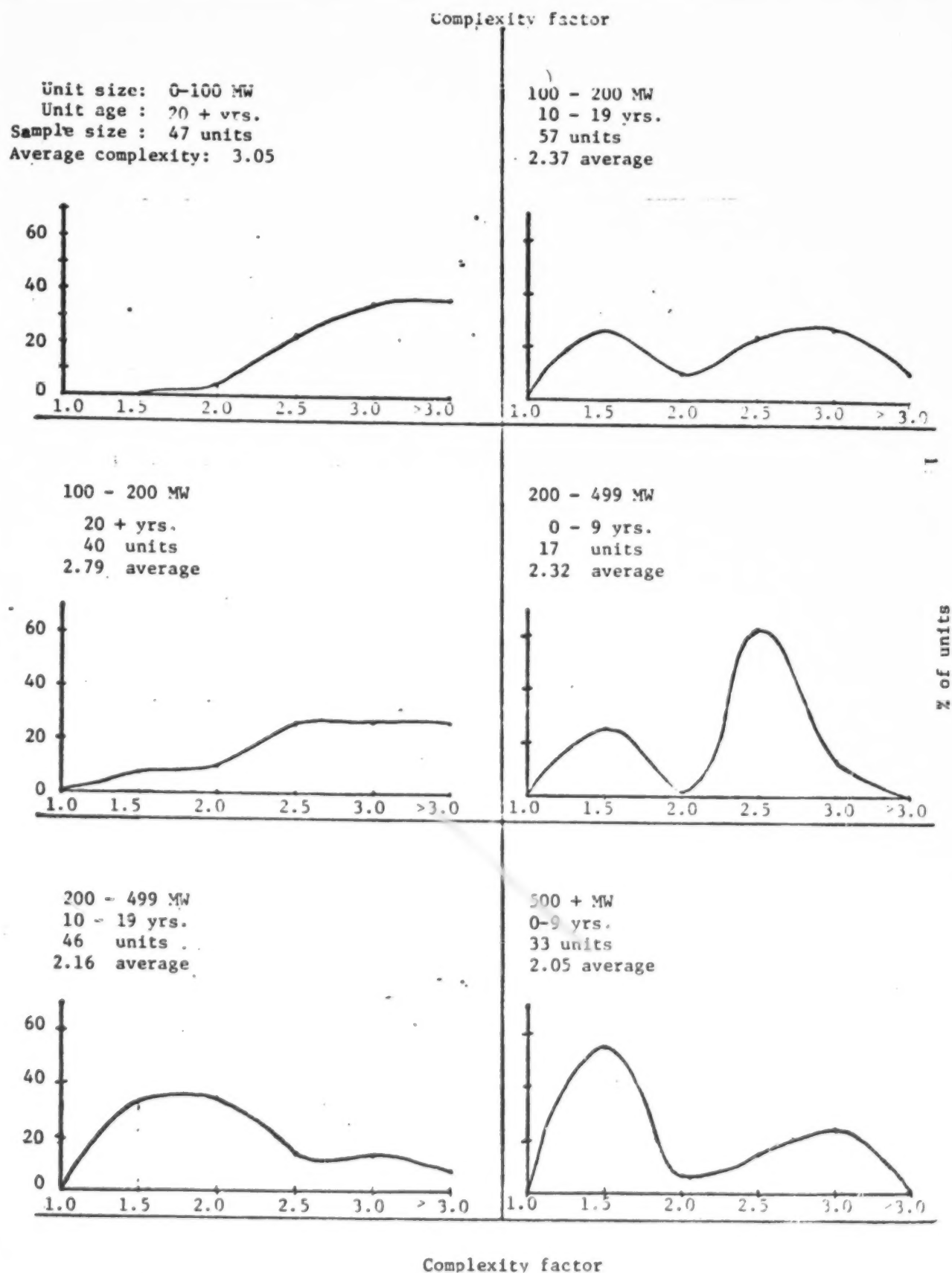


Figure 2: Distributions of Complexity Factor